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Optimising the timing of visual surveys of crabeater seal abundance: haulout behaviour as a consideration

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Abstract. The most practical means of estimating pack-ice seal abundance is by conducting visual surveys from ships and aircraft. However, only those seals hauled out on the ice are 'available' to such surveys, and additional information on haulout behaviour is required to adjust counts of seals on the ice to estimate the total population size. Consideration of the optimal time to undertake visual surveys with respect to availability is important to ensure that bias and uncertainty in the abundance estimate are minimised for a fixed survey effort. In order to assess the optimal time for conducting visual surveys of crabeater seals (*Lobodon carcinophaga*), satellite-linked dive recorders were attached to 24 adult seals in the pack-ice off east Antarctica to record haulout behaviour over a 4-month period from mid-September to mid-January. The optimal time for visual surveys within these four months was December to mid-January (after the pupping season) when a high, relatively constant proportion of seals were hauled out over a period of 6–7 h during daylight, and when variation in haulout behaviour between seals was low. Despite the necessity for breeding seals to haul out continuously for extended periods during the pupping season, this was not a preferred time for visual surveys because variability in haulout behaviour between breeding and non-breeding seals was high. The efficiency of surveys before pupping was limited by the relatively short time during daylight when both the proportion of seals hauled out was high and variability in haulout behaviour among seals was small.

Introduction

The Convention for the Conservation of Antarctic Marine Living Resources aims to manage harvesting of living resources in the Southern Ocean such that ecological relationships between harvested and dependent species are maintained (Edwards and Heap 1981). Putting this principle into practice for management of the krill fishery in the Southern Ocean requires building multispecies models for the krill-based ecosystem to predict the effects of harvesting on both krill and krill-dependent species (Butterworth 1986). Reliable data on the abundance of key species is critical to the building of such models (Butterworth 1986), but the lack of such data for krill predators is a major impediment to modelling the krill-based ecosystem (Nicol *et al*. 2000).

As an abundant, large-bodied consumer of krill, the crabeater seal (*Lobodon carcinophaga*) is a critical component of the krill-based ecosystem in the Southern Ocean and the major pack-ice seal species potentially affected by krill harvesting. Crabeater seals are distributed throughout the pack-ice surrounding Antarctica, foraging throughout the ice-covered ocean for krill and hauling out onto ice floes to rest and breed.

The Antarctic Pack-Ice Seal Program (APIS) is a recent, major initiative by the Scientific Committee on Antarctic Research's Expert Group on Seals that aims to estimate the regional and circumpolar abundance of crabeater and other pack-ice seal species (Anon. 1994). As part of the APIS program, the Australian Antarctic Division undertook the task of estimating the abundance of pack-ice seals, including the crabeater seal, in the pack-ice off east Antarctica between longitudes 60°E and 150°E. This survey region straddles 4000 km of Antarctic coastline, and in winter may extend up to 1000 km northward to the edge of the pack-ice.

The most practical means of estimating the abundance of pack-ice seals is by conducting visual surveys from ships and aircraft. However, only those seals hauled out on the ice are 'available' to such surveys, and additional information on haulout behaviour is required to adjust counts of seals on the ice to estimate the total population size. Therefore, estimating availability resulting from haulout behaviour is an essential part of the abundance-estimation procedure for pack-ice seals (and, more generally, for many marine mammal species: Eberhardt *et al*. 1979) that needs to be considered in the planning, implementation and analysis phases of work.

Given the large size and remoteness of the survey region, and the substantial logistic commitment and organisation required to undertake a survey over that region, an important consideration in planning was the optimal time (within year and within day) for survey work. One of several aspects to consider in optimising the timing is availability resulting from haulout behaviour. In this paper I quantify the haulout behaviour of a sample of crabeater seals over the period late-winter to mid-summer (mid-September to mid-January) and

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assess the optimal time within this period for visual surveys of this species with respect to availability.

Methods

Haulout behaviour of crabeater seals was recorded using ARGOS satellite-linked dive recorders (SDRs) (half-watt, model 3.10, Wildlife Computers). SDRs were deployed on crabeater seals during early season (September–October) voyages of the Antarctic Division's research and resupply vessel R.S.V. *Aurora Australis*. As the SDRs were expected to remain on the seals until moulted off in January or February, I aimed to assess haulout behaviour over the 4-month period, mid-September to mid-January. This was the period within which large-scale visual surveys were planned to occur. The 4-month period covers the times from near maximum to near minimum ice extent, and straddles the times before, during, and after the pupping season, which extends from early October to early November (Southwell *et al*. 2003).

Adult seals were chemically restrained while hauled out on ice floes with a combination of midazolam and pethidine administered from a dart gun at dose rates of 0.15–0.40 and 1–3 mg kg^{-1} respectively (Tahmindjis *et al*. 2003). The seals remained sedated for ~30 min while SDRs were glued to the pelage, then a combination of naloxone and flumazenol was administered to reverse the sedation. Following application of the reversal agents, seals were observed for a further 30 min to ensure a satisfactory recovery. In total, 24 SDRs were deployed between longitudes 70°E and 120°E over a 6-year period 1994–99, 17 on males and seven on females (Table 1). Of these 24 SDRs, six were deployed in mid-September before pupping, 17 between early October and mid-November, when pups are present on the ice (Southwell *et al*. 2003), and one in December after pupping. Four of the 24 adults were captured in the presence of a pup, and six of the remaining 20 seals displayed a period of extended, continuous haulout subsequent to capture that was probably associated with the birth of a pup (Southwell 2004).

The SDRs measured conductivity (wet/dry) at 10-s intervals and summarised these data into 20-min periods for transmission to ARGOS satellites. A 20-min period was summarised as being wet or dry if the majority of 10-s measurements were wet or dry respectively. I assumed that wet and dry 20-min periods indicated that a seal was in the water or on the ice, respectively, for the full 20 min. This assumption is supported by observations reported in Bengtson and Stewart (1992), Nordøy *et al.* (1995) and Bengtson and Cameron (2004), that once crabeater seals haul out or enter water, they usually remain on the ice or in the water for several hours. The 72 × 20-min periods in a day commenced on the GMT hour, one-third GMT hour or two-thirds GMT hour (i.e. 00:00–00:20, 00:20–00:40 … 23:40–24:00 GMT). As the SDRs also provided information on location as latitude and longitude each time a transmission was received by an ARGOS satellite, it was possible to convert GMT periods to solar periods.

Haulout patterns were examined in relation to time of year, time of day and sex from data pooled across years. As breeding seals are known to haul out continuously between giving birth and weaning a pup (Southwell 2004), time of year was stratified into five periods related to the stage of the pupping season in an effort to minimise variability in haulout behaviour within periods and maximise variability between periods. The five stages were defined in relation to the presence of pups on ice as found in east Antarctica by Southwell *et al*. (2003): pre-pupping (before 1 October), early pupping (1–20 October), peak pupping (21 October – 10 November), late pupping (11–30 November) and post-pupping (after 30 November). Time of day was considered in relation to the 20-min periods used in the data-summarising process

Table 1. Date, location and duration of transmissions for satellite-linked dive recorders deployed on 24 adult crabeater seals in east Antarctica from 1994 to 1999

The sex and presence or absence of a pup at the time of capture for each seal is also shown. M, male; F, female; p, pup present at time of capture; np, no pup present at time of capture

Date of capture	Latitude	Longitude	Sex and presence or absence of a pup	Duration of transmission period (days)	Date of last transmission
18.ix.1994	61°24′S	78°22′E	M, np	56	13.xi.1994
20.ix.1994	63°20′S	75°32′E	F, np	42	1.xi.1994
20.ix.1994	63°23′S	74°58′E	M, np	91	20.xii.1994
22.ix.1994	63°23′S	74°58′E	M, np	56	17.xi.1994
30.ix.1995	62°34′S	98°03′E	M, np	54	23.xi.1995
2.x.1995	62°43′S	88°07′E	M, np	88	29.xii.1995
15.x.1996	62°53′S	93°01′E	M, np	85	8.i.1997
16.x.1996	62°27′S	88°08′E	M, np	84	8.i.1997
16.x.1996	62°29′S	88°04′E	F, np	75	30.xii.1996
18.x.1996	62°09′S	85°21′E	F, np	52	9.xii.1996
23.x.1996	64°17′S	74°70′E	M, p	1	24.x.1996
25.x.1996	65°27′S	75°35′E	M, np	81	14.i.1997
9.x.1997	62°39′S	105°21′E	F, np	0	9.x.1997
10.x.1997	62°10′S	101°46′E	F, p	55	4.xii.1997
10.x.1997	62°10′S	101°46′E	M, p	85	3.i.1998
12.x.1997	62°34′S	88°56′E	M, np	80	31.xii.1997
13.x.1997	62°22′S	83°05′E	M, np	82	3.i.1998
13.x.1997	62°22′S	83°05′E	M, p	38	20.xi.1997
15.x.1997	62°40′S	71°55′E	F, np	49	3.xii.1997
16.x.1997	63°42′S	67°55′E	F, np	40	25.xi.1997
19.x.1997	63°11′S	67°46′E	M, np	43	1.xii.1997
9.xi.1998	64°31′S	108°24′E	M, np	57	5.i.1999
16.xi.1998	65°31′S	78°48′E	M, np	49	4.i.1999
15.xii.1999	64°30′S	117°40′E	M, np	30	14.i.2000

described above, and the four 6-h periods 0300–0900, 0900–1500, 1500–2100 and 2100–0300 hours. Data from the first two days after capture were discarded from analysis to avoid any potential effect of capture and sedation on haulout behaviour. Individual seals were considered for analysis in each pupping stage only if data were available for ≥5 days in the stage. Within each stage and for each 20-min and 6-h period, I calculated the proportion of time that each seal was taken to be on the ice. The means and standard deviations of these proportions across seals were then calculated for each 20-min and 6-h period in each pupping stage after applying an arcsine transformation to normalise the data. Differences in the mean proportion of time hauled out by males and females in those 6-h periods and pupping stages when data were available for ≥3 seals of each sex were tested using a *t*-test on arcsine-transformed data.

Results

In total, 22 of the 24 SDRs deployed provided data for ≥30 days (Table 1); the remaining two SDRs either failed to transmit any data or transmitted for a single day only. After filtering the data to meet the conditions outlined above, sample sizes (number of male/female seals) for the five pupping stages were 3/1, 9/2, 12/6, 13/8 and 11/1 respectively (Table 2).

Haulout behaviour, averaged across all seals, exhibited a unimodal pattern in all five stages of pupping, the pattern being most pronounced before and after pupping (Fig. 1). In all periods the peak in haulout occurred close to midday, and minimum haulout occurred across the hours of darkness. Similar unimodal patterns with peak haulout around midday have been documented for the summer months by Bengtson and Stewart (1992) and Bengtson and Cameron (2004). The mean proportion of days hauled out during the time of peak haulout (i.e. the 20-min intervals around midday) ranged between 0.70 and 0.80 across the five stages of pupping (Fig. 1). Haulout increased from low levels shortly after sunrise and returned to low levels shortly before sunset in all periods, suggesting a direct effect of the light/dark regime on diving and haulout behaviour.

During the pre- and post-pupping stages, variability in haulout behaviour among seals was greater during the time of transition from water to ice and *vice versa* than in the times of peak haulout or diving. In contrast, during the early and peak pupping stages variability among seals was greatest during the hours of darkness. This latter result is likely to be a consequence of differing haulout behaviours of breeding and non-breeding seals: breeding seals haul out continuously between giving birth and weaning a pup (Siniff *et al*. 1979; Southwell 2004), whereas non-breeding seals probably continue with the strongly unimodal pattern observed in all seals before and after pupping. The greatest difference in these two haulout behaviours is manifested at night.

Sample sizes were sufficient (≥3) to allow comparison of haulout behaviour between sexes in the peak- and late-pupping stages only, although even in these cases the small sample sizes, particularly for females (Table 2), limited the power of such tests. None of the *t*-tests achieved significance at the 5% level, although comparisons for the 0300–0900-hour and 2100–0300-hour periods in the late-pupping stage were close to significant (Table 2).

Table 2. Proportion of time spent hauled out by male and female crabeater seals in each of five stages of the pupping season and four 6-h periods of the day, and results of *t*-tests comparing the mean proportion of time hauled out by males and females

n_m = no. of males, n_f = no. of females, CL = 95% confidence limits, P = P-value for *t*-test. CLs and *t*-tests were computed only if $n \geq 3$

Stage of pupping season	Time of day (hours)	Male Mean	Male CL	Female Mean	Female CL	P
Pre-pupping	0300–0900	0.24	0.01–0.60	0.06	–	–
(n_m = 3, n_f = 1)	0900–1500	0.82	0.45–1.00	0.62	–	–
	1500–2100	0.28	0.00–0.76	0.27	–	–
	2100–0300	0.01	0.00–0.09	0.04	–	–
Early-pupping	0300–0900	0.72	0.48–0.98	0.57	–	–
(n_m = 9, n_f = 2)	0900–1500	0.91	0.84–1.00	0.78	–	–
	1500–2100	0.64	0.38–0.94	0.66	–	–
	2100–0300	0.57	0.22–0.95	0.54	–	–
Peak-pupping	0300–0900	0.67	0.50–0.86	0.57	0.32–0.81	0.429
(n_m = 12, n_f = 6)	0900–1500	0.86	0.72–0.90	0.80	0.67–0.92	0.968
	1500–2100	0.61	0.40–0.83	0.49	0.16–0.81	0.964
	2100–0300	0.50	0.21–0.78	0.34	0.01–0.72	0.928
Late-pupping	0300–0900	0.47	0.35–0.57	0.31	0.17–0.46	0.076
(n_m = 13, n_f = 5)	0900–1500	0.72	0.67–0.82	0.71	0.55–0.85	0.812
	1500–2100	0.34	0.16–0.52	0.30	0.23–0.38	0.999
	2100–0300	0.17	0.05–0.27	0.02	0.00–0.06	0.055
Post-pupping	0300–0900	0.55	0.45–0.65	0.28	–	–
(n_m = 11, n_f = 1)	0900–1500	0.79	0.72–0.87	0.68	–	–
	1500–2100	0.40	0.33–0.46	0.80	–	–
	2100–0300	0.03	0.01–0.05	0.07	–	–

Discussion

Availability is just one issue that must be considered in planning surveys of the abundance of pack-ice seals. Other aspects of planning, in particular the logistics of undertaking visual surveys from ships and/or aircraft over remote and vast expanses of pack-ice, are crucial but are not addressed in this paper. Ideally, and considering only the issue of availability, visual surveys would best be carried out when the maximum proportion of seals are hauled out on the ice, and when variability between seals in their haulout behaviour is small. Timing surveys to optimise these two criteria would ensure that correcting counts of seals on the ice for availability occurs with the least uncertainty. This study indicates that, over the 4-month period considered, the time after pupping (December – early January) is optimal for survey work with respect to availability. At this time of year the proportion of seals hauled out on ice is high and relatively constant (~0.80) over 6–7 h of daylight, and is relatively invariant between individual seals during this 6–7-h interval. Undertaking visual surveys at this time of year would ensure that optimal haulout conditions exist for the longest time within any single day, thereby maximising the effort that can be optimally applied each day in visual surveys. Undertaking visual surveys in the 6–7-h interval of peak haulout would maximise the encounter rate, which would minimise variability in encounter rate given a fixed survey effort. A final advantage of surveying at this time of the day and year is that uncertainty in the estimate of availability, which contributes to uncertainty in the overall abundance estimate, would be minimised because variability in haulout behaviour among seals is minimal.

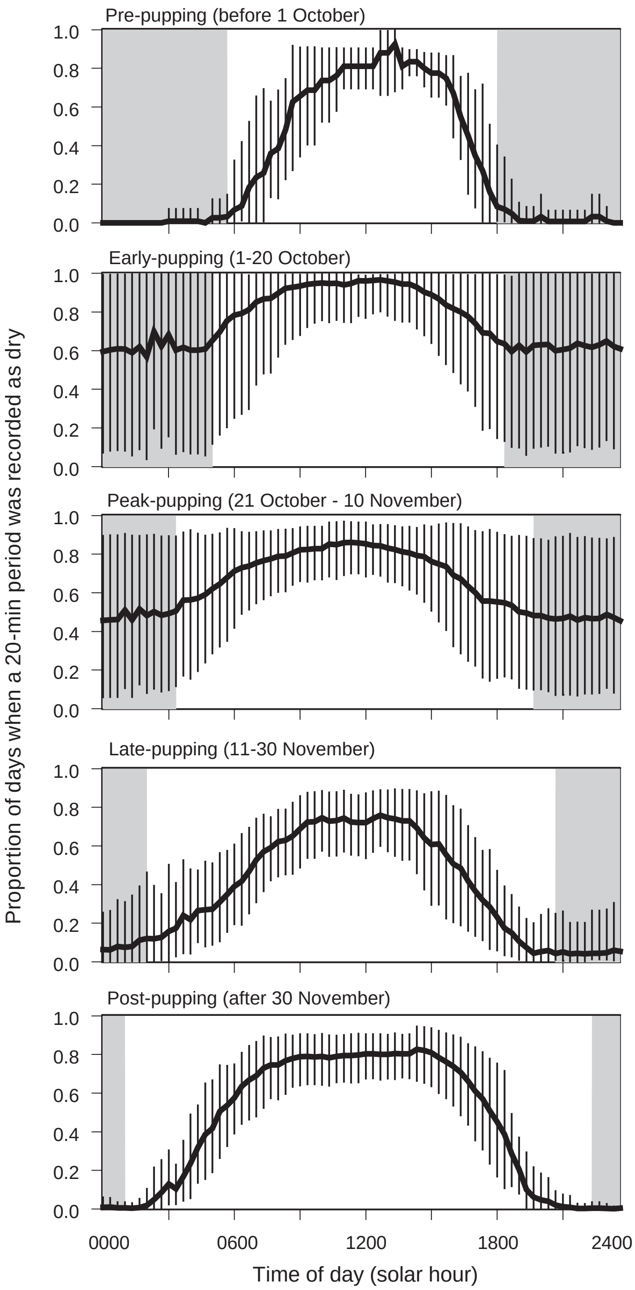

Fig. 1. Diel haulout profiles for 22 adult crabeater seals in east Antarctic during five periods of the year from September to January. The bold line is the mean (across all seals) proportion of days when a 20-min period was recorded as dry, calculated across seals for each 20-min period. The vertical lines indicate among-seal variation around the mean (±1 s.d.). The shaded areas indicate approximate times when the sun was below the horizon, averaged across each seal's daily location.

Bengtson and Cameron (2004) concluded, from data over a longer period (11 months) but derived from fewer seals, that February was an optimal period for visual surveys. Their haulout profile from five seals in February was similar to the results shown here for the post-pupping period, particularly with respect to a plateau of maximum haulout sustained over several daylight hours, whereas, unlike this study, their profile from two seals in December showed no sustained plateau. The difference between studies in results for December may be an artefact of the small sample size ($n = 2$) at this time in Bengtson and Cameron's (2004) study. It is possible that sustained, high haulout during the daylight hours may occur across the entire 3-month period from December through February. However, confirmation of this is difficult because crabeater seals moult in January and February (Kooyman 1981), making attachment of SDRs difficult at this time.

Of the other periods considered in this study, the pre-pupping period has the disadvantage of optimal haulout conditions occurring for only a short period each day, thereby limiting the time available for efficient survey work. On the other hand, during the pupping season mean haulout is sustained at high levels across several hours each day, but variability among seals is low for only short periods each day, again limiting the time available for efficient survey work. The high variability in haulout behaviour between seals in the pupping season is likely to result from differential haulout patterns of breeding and non-breeding seals. Some of the seals in this study showed strongly bimodal patterns throughout the pupping period, as did the two seals in October in Bengtson and Cameron's (2004) study, whereas others hauled out continuously for extended periods (Southwell 2004). The effect of these differing haulout behaviours would be manifested in high variability among seals outside the time of peak haulout.

A further reason for timing surveys outside of the pupping season is that estimates of availability for the population may be less biased at these times than during the pupping season. Ideally, haulout behaviour should be recorded from a random sample of seals to obtain a representative estimate of availability for the entire population. In practise, however, seals can be captured for deployment of SDRs only when hauled out on ice floes. This restriction may impose some bias in quantifying haulout behaviour with respect to the entire population, owing to differential behaviour and capture probability of breeding and non-breeding seals. For example, if seals are captured during the breeding season at times outside of peak haulout, there will be a greater chance of catching breeding seals than non-breeding seals because a smaller proportion of non-breeding seals than breeding seals will be hauled out at these times. This would lead to a positive bias in the estimated proportion of time spent on ice because the ratio of breeders to non-breeders in the sample is positively biased. There is less chance of such bias occurring in the pre- and post-pupping periods because seals are less variable in their haulout behaviour at these times.

Similarly, there is potential for bias in estimation of availability in all stages of pupping because of differential capture probability of males and females. The preponderance of males (17) over females (7) in the sample of captured seals more likely reflects the difficulty of catching females in the breeding season, when males within male–female pairs are extremely aggressive towards anyone approaching the female, than the true sex ratio of the population. Given a likely sex bias in the capture sample, if there were also differential haulout behaviour by the sexes then estimation of availability for the population by simply pooling data across all captured animals (as in Fig. 1) would result in a biased estimate of haulout probability for the population. Fortunately, with no evidence in this study of differential haulout behaviour between the sexes in the peak- and late-pupping stages, the estimates of haulout probability for the entire population during these and possibly the other stages of pupping in Fig. 1 should be free of any sex-related bias. Consequently, the estimates of haulout probability obtained from this study are not only useful for determining the optimal time for visual surveys, but also for correcting counts obtained in visual surveys.

Although this paper has focussed only on the crabeater seal as a target species for abundance estimation, the APIS program aims to estimate the abundance of not only the crabeater seal but also other species of pack-ice seal from the same visual survey effort. As the pupping seasons (and hence haulout patterns) of pack-ice seal species are not entirely consistent in time (Southwell *et al*. 2003), and considering that haulout behaviour outside of the pupping season may also differ among species, an optimal time with respect to availability of any one of these species may be suboptimal for other species. Finding the best time for a single visual survey effort of several species with differing haulout behaviours may therefore require selecting a time that is, with respect to availability, marginally suboptimal for each species but collectively optimal for all.

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